Aging and visual pattern detection

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A single psychophysical experiment evaluated observers' ability to detect visual patterns embedded in noise; effects of stimulus complexity and observer age were also evaluated. Eighteen younger and older observers participated in the experiment (mean ages were 20.3 and 72.6 years, respectively). On any given trial, observers were presented with two successive temporal intervals; a dotted visual pattern embedded in noise appeared in one temporal interval, whereas a completely random spatial distribution of dots appeared in the other. The observers' task was to indicate which temporal interval contained the pattern. For all observers, there were large effects of both stimulus complexity and amount of noise. Plots of pattern detection accuracy as a function of complexity were determined for both younger and older adults. As a group, the younger adults were able to tolerate higher amounts of complexity (than older adults) and still perform at a threshold level of performance ($d' = 1.0$). Despite this overall difference in performance between the age groups, there was a large amount of interobserver variability, such that the pattern detection performance of some individual older adults matched or exceeded that of a sizeable number of younger adults—aging is therefore not accompanied by a uniform or necessary decline in pattern detection.

Introduction

Randolph Blake's contributions to vision science have been strong and highly influential for more than a half century. Across hundreds of published scientific articles, he and his colleagues have studied a wide variety of topics ranging from binocular vision (e.g., Alais & Blake, 1999; Blake, Yu, Lokey, & Norman, 1998; Harrad, McKee, Blake, & Yang, 1994; Fukuda & Blake, 1992; Tong, Meng, & Blake, 2006) to common fate and the importance of temporal structure for the perception of form (e.g., Blake, Rizzo, & McEvoy, 2008; Lee & Blake, 1999) to motion perception (e.g., Gros, Blake, & Hiris, 1998; Tadin, Lappin, Gilroy, & Blake, 2003) to synesthesia (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002) and cat psychophysics (e.g., Blake, Cool, & Crawford, 1974; Blake & Holopigian, 1985).

In their 2008 study investigating aging and the perception of visual form from temporal structure, Blake et al. (2008) used a unique form of common fate. In one condition, elements belonging to the stimulus shape (vertical or horizontal rectangle) reversed their local directions of motion at the same times (i.e., together), whereas stimulus elements belonging to the background reversed their local directions of motion at other times. Thus the perception of shape in this condition was enabled by the simultaneity in motion direction reversal. In a control condition, the perception of shape (again a vertical or horizontal rectangle) was defined by a difference in average luminance between object and background. Blake et al. found a substantial adverse effect of age when the stimulus shape was defined by differences in temporal structure (TS), but not when the stimulus shape was defined by differences in luminance (LUM). In this luminance condition, the shape discrimination performance exhibited by the younger and older observers was equivalent. According to Blake et al. (2008;

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p. 185) “Both groups produced comparable thresholds for discriminating shape from luminance contrast (older: 0.12 [SE = 0.04] vs. young: 0.11 [SE = 0.02]).” With regards to the TS condition where there was a large and negative effect of age (see Figure 4b of Blake et al.), Blake et al. (2008) indicated (p. 187) that “recent modeling work on perception of form from TS suggests to us that the differences in performance between our two participant groups on the TS task may have to do with the strength or the precision of the time-varying neural signals generated by TS in these displays.” At this point, it is important to keep in mind that aging is associated with deterioration in performance for many motion-related tasks, such as judgments of motion direction (Atchley & Andersen, 1998; Ball & Sekuler, 1986; Bennett, Sekuler, & Sekuler, 2007; Billino, Bremmer, & Gegenfurtner, 2008; Pilz, Miller, & Agnew, 2017; Shain & Norman, 2018), and speed (Norman, Burton, & Best, 2010; Norman, Ross, Hawkes, & Long, 2003; Raghuram, Lakshminarayanan, & Khanna, 2005; Snowden & Kavanagh, 2006). A good review of aging and its effects upon motion perception was provided by Billino and Pilz (2019).

The research of Blake et al. (2008) demonstrated that visual shape perception (at least for simple shapes) is unaffected by aging when temporal changes are either absent or irrelevant. One would perhaps therefore expect that age-related differences would be small or nonexistent for other visual pattern or shape tasks that also do not involve motion or temporal change (since Blake et al.’s hypothesis is that aging is accompanied by “changes in the strength or precision of time-varying neural signals”). For non-shape-related visual tasks using stationary visual stimuli, the results are mixed, although older adults perform well for many of them (i.e., no adverse effect of age). For example, older adults perform well at tasks requiring (1) the judgment of contour orientation (see the control experiment of Bennett et al., 2007), (2) the discrimination of length (Norman, Holmin, & Bartholomew, 2011), (3) the visual perception of object size (Norman, Baig, Eaton, Graham, & Vincent, 2022), (4) the detection of differences in Euclidean, affine, projective, or topological geometric properties (see results concerning accuracy in Meng et al., 2019), and (5) the stereoscopic discrimination of ordinal depth relationships (Experiment 1 of Norman et al., 2008). For other tasks using stationary visual stimuli, effects of age only occur for particular condition(s). For example, Habak and Faubert (2000) found no effect of age when observers discriminated the orientation of first order (i.e., luminance defined) gratings, but a significant effect of age did occur when the observers performed the same task for second order (contrast defined) gratings. Similarly, a study by Legault, Allard, and Faubert (2007) found no effect of age for detection of a bell-shaped curve, but did obtain an effect of age for detection of compressed arcs and quadratic curves. One can see that older observers often perform well for tasks involving stationary visual stimuli, but exceptions certainly do occur (e.g., symmetry detection, see Herbert, Overbury, Singh, & Faubert, 2002).

At this point it is important to keep in mind that Blake et al. (2008) found no effect of age for the discrimination of simple luminance-defined shapes. This result may not necessarily extend to the judgment of more complex shapes, because complexity has strong modulating effects upon visual pattern or shape perception and the influence of complexity upon pattern detection has not yet been adequately evaluated for older adults. In 1977, Uttal and Tucker asked younger observers to detect dotted patterns embedded in various amounts of noise dots. The task was 2AFC (two alternative forced choice). On any given trial, a dotted pattern would be presented in one temporal interval, and a completely random spatial arrangement of dots would be presented in the other interval. The observers simply indicated which interval (first or second) contained the pattern. Uttal and Tucker employed dotted patterns that varied in perceived complexity (i.e., “Chipman patterns”, see Chipman, 1972, and table 1 & figure 2 of Uttal & Tucker). Uttal and Tucker found a strong modulating effect of perceived complexity—with other factors held constant, the overall detection performance was 62% correct for the most complex patterns and 96% correct for the least complex (i.e., most simple) patterns.

The primary goal of the current experiment was quite straightforward. Prior research by Blake et al. (2008), Meng et al. (2019), and Norman and Higginbotham (2020) all suggest that effects of age are either minimal or nonexistent for shape- or pattern-related visual tasks when motion or temporal change is not a factor. However, none of those prior studies manipulated complexity, even though it is known to strongly modulate the ability to visually detect/perceive shape in the presence of noise (see Figure 4 of Uttal & Tucker, 1977). Whether variations in complexity differentially affect the shape detection abilities of younger and older adults is completely unknown. The primary goal of the current experiment was therefore straightforward, to fill in this gap in our understanding. A secondary purpose of the current experiment was to verify the validity of the results obtained by Uttal and Tucker (1977). Although their study was of fundamental importance, these researchers nevertheless only evaluated the detection abilities of three highly experienced observers. Our current experiment evaluated the pattern detection abilities of six times as many observers (18 vs. 3), none of which were experienced with this task.

Method

Apparatus

The experimental stimuli were generated and presented by an Apple M1 iMac computer. This computer was also used to record the observers' responses.

Experimental Stimuli

The specific patterns to be detected were identical to a subset of stimuli used in a former investigation by Uttal and Tucker (1977); the eight patterns used in the current experiment are shown in Figure 1 (the pattern numbers indicated are the same as those used by Uttal & Tucker). The complexity of the patterns increases from upper-left (the most simple) to bottom-right (the most complex). The complexity scores (i.e., magnitudes) for each of the stimulus patterns are specified in the abscissa of Figure 2; these complexity scores were taken directly from Table 1 of Uttal and Tucker and were derived from observers' judgments of perceived complexity of these same patterns (Chipman, 1972; also see Chipman, 1977). In Chipman's (1977) study, students and staff at Harvard University were asked to perform (p. 273) "magnitude estimation without a standard. Subjects received the following

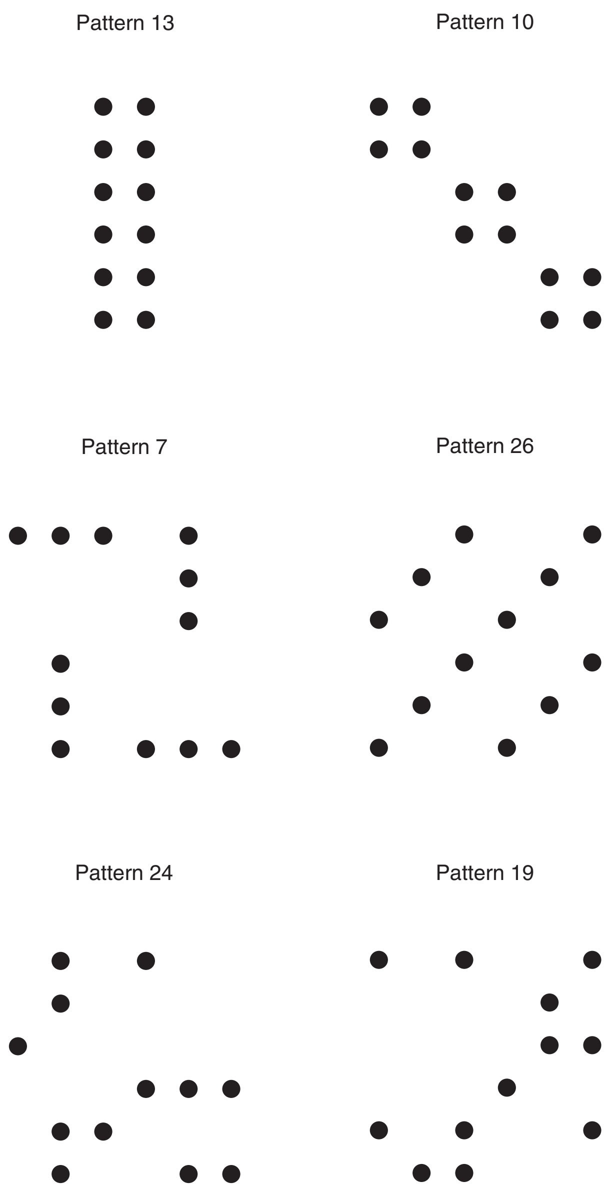

Figure 1. A diagram illustrating the eight dotted stimulus patterns used in the current experiment. These patterns (a subset of those used by Uttal and Tucker, 1977) increase in complexity from upper-left to bottom-right.

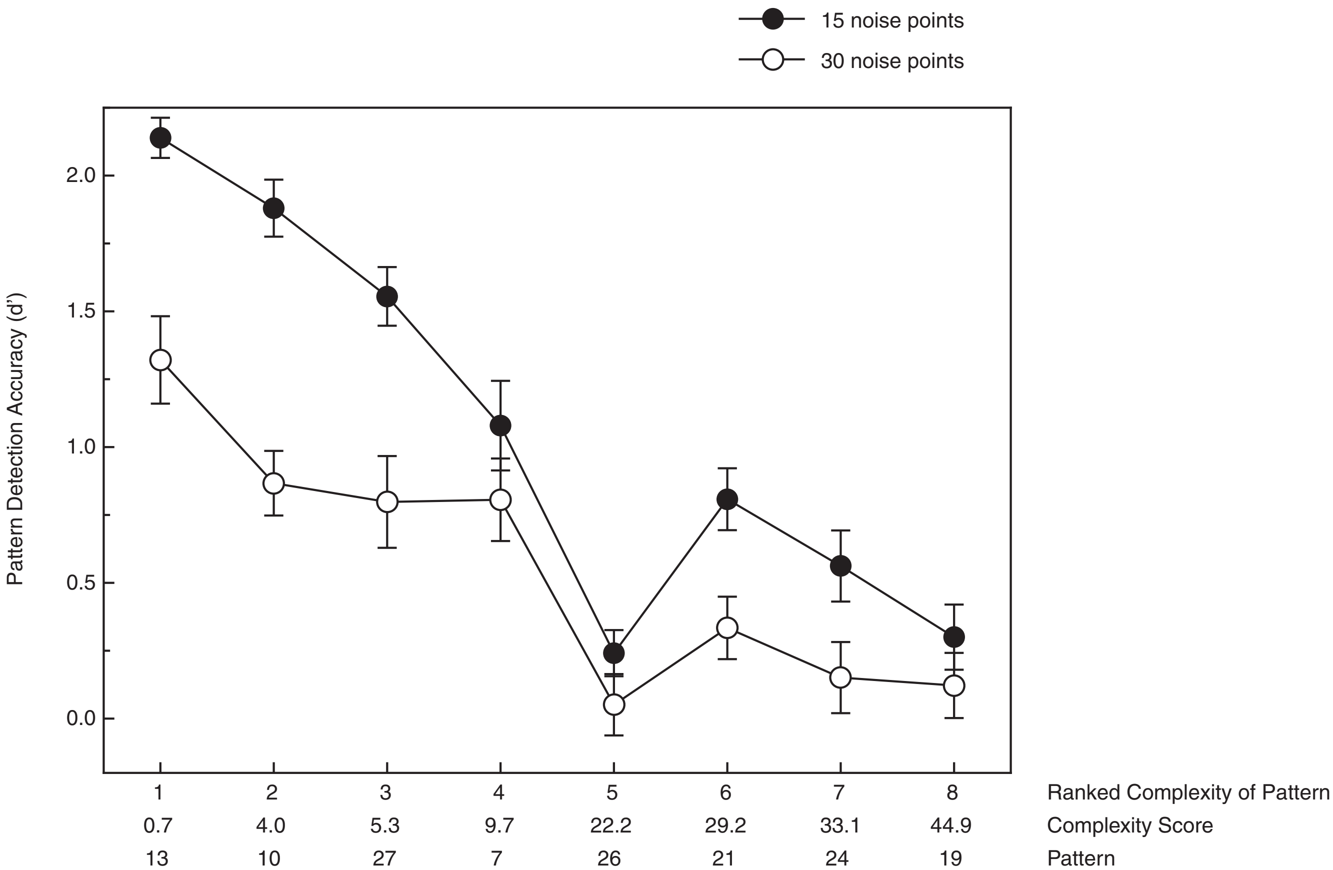

Figure 2. The observers' pattern detection accuracies (d' values) plotted as a function of complexity of the stimulus patterns (the complexity increases from left to right). The results for the low-noise and high-noise conditions are indicated by the filled and open circles, respectively. The error bars indicate $\pm$ 1 *SE*. One can readily see that the observers' detection performance decreased with increasing complexity of the stimulus patterns.

instructions: You are to estimate the complexity of these patterns. Give the first pattern whatever number seems to you to represent how complex the pattern is. If the next pattern seems twice as complex, give it a number twice as large. If it seems half as complex, give it a number half as large, and so on... Use whatever numbers are necessary to represent the relationship between the patterns." In our current experiment, these stimulus patterns (Figure 1) were always camouflaged by being embedded in a randomly distributed set of "noise" dots (i.e., the 12 stimulus dots were embedded within either a purely random spatial distribution of 15 or 30 noise dots). There were two temporal intervals within each trial: one interval contained only "noise" (uniform random distribution of dot positions) while the other contained one of the stimulus patterns (Figure 1) embedded in noise. Notice that there were either 27 or 42 total dots in the temporal interval containing the stimulus pattern (12 pattern dots plus either 15 or 30 noise dots). In order to make the total number of dots equivalent across the two temporal intervals within a trial, random spatial distributions of either 27 or 42 dots were presented in the "noise" temporal interval of each trial, whichever was appropriate (i.e., depending upon whether the condition was low noise or high noise). The stimulus dots themselves were bright yellow, rendered with antialiasing, and were presented against a black background. The spatial extent (horizontal and vertical) of the dotted stimuli themselves was approximately 3.5° visual angle. The two temporal intervals of each trial were presented successively (for 1.25 seconds each) within a 600 $\times$ 600 pixel window. This stimulus duration (1.25 seconds) was selected after pilot testing as being the value that best illustrates the overall function relating the observers' detection performance and stimulus complexity (i.e., produces values of d' that range from near zero to more than 2.0). The viewing distance was 114.6 cm.

Procedure

After being presented with both temporal intervals of a trial, the observers' task was simply to indicate which

temporal interval (first or second) contained a pattern. Each participant made a total of 320 judgments (20 trials for each combination of eight stimulus patterns and two amounts of obscuring noise: 15 and 30 noise dots). The order of stimulus patterns and amount of noise was determined randomly for each individual observer. No feedback regarding performance was given during these 320 experimental trials. The observers were given a short break (e.g., 2–3 minutes) halfway through the 320 total trials.

To make sure that all observers completely understood the stimulus and task, they participated in a block of 40 trials before beginning the actual experiment. The eight stimulus patterns presented in these familiarization trials were similar to those used in the actual experiment; the particular stimulus patterns were patterns 28, 29, 2, 15, 5, 17, 25, and 18 (listed in order of increasing complexity) used in the prior investigation by Uttal and Tucker (1977). In order to help explain the task to the observers, the pattern dots in these familiarization trials were rendered in red, whereas the noise dots were yellow. All of the younger and older observers (except one, as described below) were able to see the patterns and indicate in which temporal interval they appeared with an accuracy of 98.9% correct (it is very important to remember that this color difference, between pattern and noise dots, *only* occurred during familiarization and did not exist during the actual experiment).

Observers

In three previous experiments involving aging and the detection and discrimination of static surfaces defined by binocular disparity (i.e., Experiments 2 & 3 of Norman et al., 2008, and Experiment 1 of Norman et al., 2006), sample sizes of eight to 10 older and younger adults gave sufficient power to detect age-related deficits. Because of this and the fact that the current experiment also involved the detection of stationary patterns, we recruited nine older and nine younger observers to participate. The mean ages of the younger and older observers were 20.3 years (ages ranged from 18-27 years, $SD = 3.0$) and 72.6 years (ages ranged from 66 to 77 years, $SD = 4.0$), respectively. For unknown reasons, one potential younger observer (20 years old) was unable to perform the task at better than chance levels, and he was therefore excluded. The observers had excellent visual acuity: the acuity of the younger and older observers measured at 100 cm was −0.144 and −0.056 LogMAR (log minimum angle of resolution), respectively (zero LogMAR represents normal visual acuity, whereas positive and negative values represent worse than and better than normal acuity, respectively). The study was approved by the Institutional Review Board of Western Kentucky University, and each observer signed an informed consent document prior to testing. Our research was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Results

Various aspects of the results are shown in Figures 2, 3, 4 and 5—these figures illustrate significant interactions involving pattern complexity (Figures 2 & 4), the overall relationship between pattern complexity and detection performance (Figure 3), as well as the overall results of individual younger and older observers (Figure 5). We evaluated our observers' sensitivity to the patterns in terms of *d′*, the perceptual sensitivity measure of signal detection theory (Macmillan & Creelman, 1991). The observers' *d′* values were subjected to a three-way split-plot analysis of variance (ANOVA; 2 age groups × 2 noise levels × 8 stimulus patterns). The results of the ANOVA showed that the observers' ability to detect the patterns was heavily influenced by stimulus complexity ($F(7, 112) = 43.6$, $p < 0.000001$; $\eta^2_p = 0.73$). The significant and large effect of stimulus complexity is readily evident in Figure 2. This figure also illustrates a significant main effect of noise ($F(1, 16) = 58.3$, $p = 0.000001$;

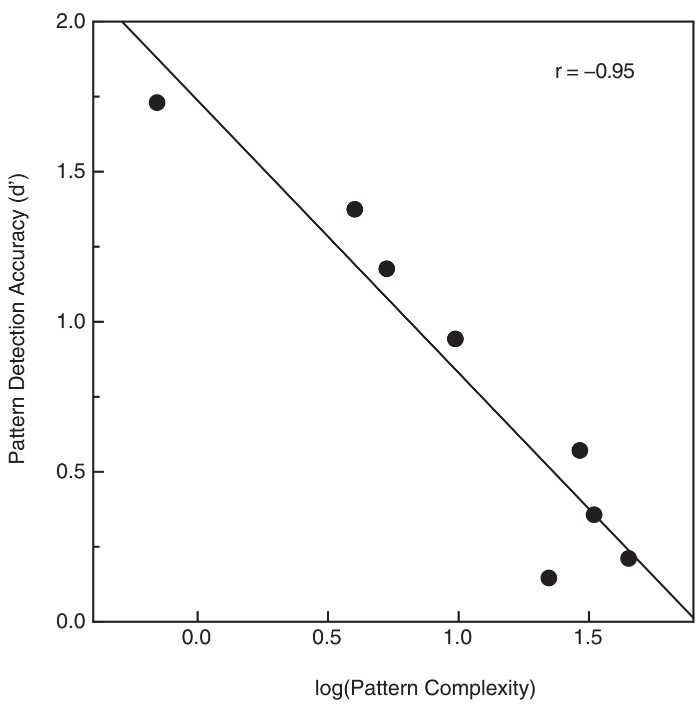

Figure 3. The observers' overall pattern detection accuracies (*d′* values) plotted as a function of log pattern complexity. The solid line indicates the best fitting linear regression.

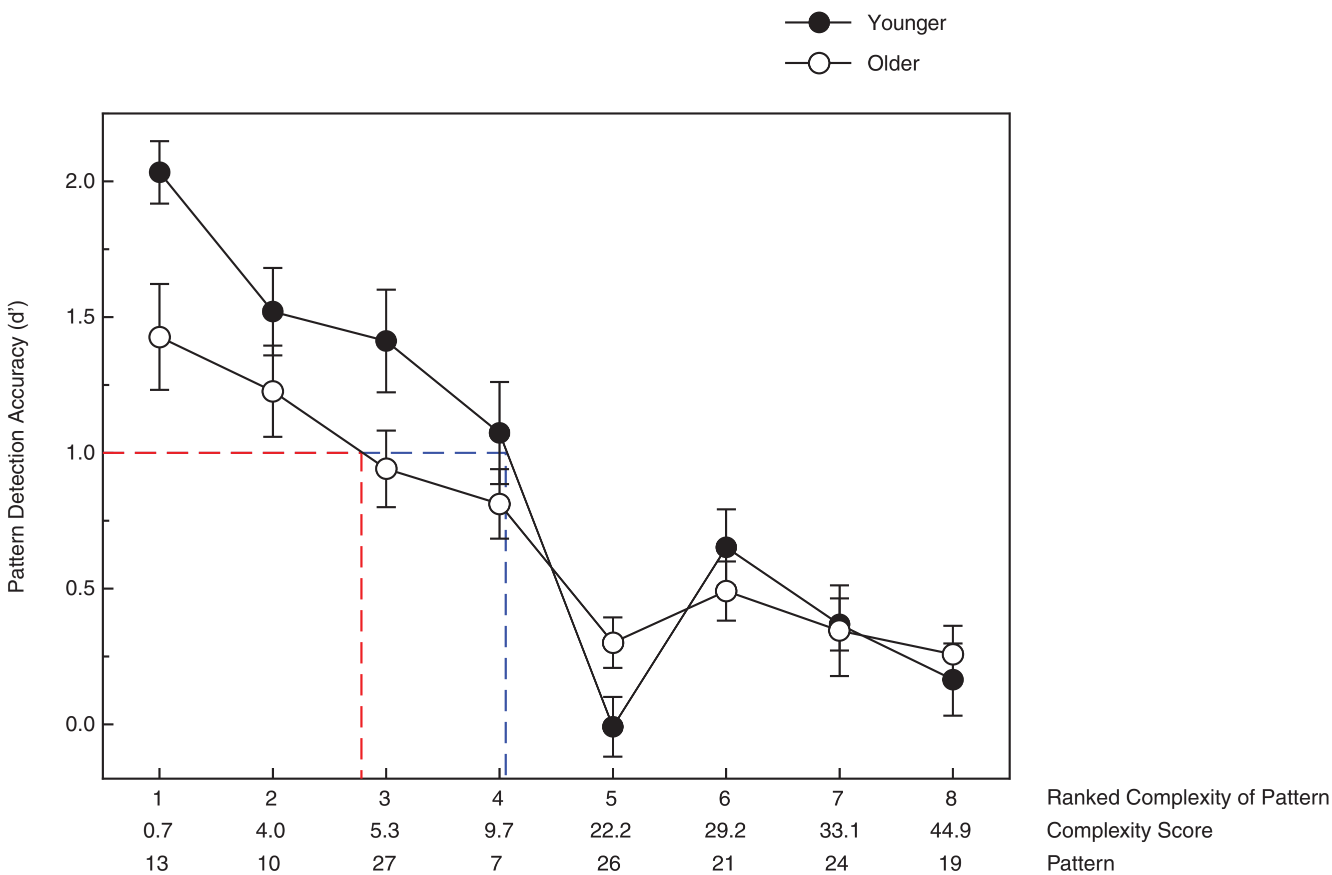

Figure 4. The younger (filled circles) and older (open circles) observers' pattern detection accuracies (d' values) plotted as a function of stimulus complexity. The dashed lines indicate what pattern complexities produce threshold performance levels (i.e., what pattern complexities result in a d' value of 1.0 for younger and older adults).

$\eta^2_p = 0.79$) and a noise × complexity interaction ($F(7, 112) = 5.1$, $p < 0.0001$; $\eta^2_p = 0.24$), such that the effect of complexity was larger for the low noise condition and smaller in magnitude for the high noise condition. The overall effect of stimulus complexity is presented in Figure 3: a linear relationship exists between log pattern complexity and the observers' pattern detection performance (Pearson $r = -0.95$, $p < 0.001$, two-tailed). Although there was no main effect of age ($F(1, 16) = 2.0$, $p = 0.18$; $\eta^2_p = 0.11$), there was nevertheless a significant age x complexity interaction ($F(7, 112) = 2.9$, $p < 0.01$; $\eta^2_p = 0.15$) that can be readily seen in Figure 4. Notice that while there was no consistent effect of age for the four most complex patterns (i.e., for complexity scores of 22.2 and higher), there was a modest effect of age for the four simplest patterns (complexity scores of 9.7 and below). The younger adults' d' values were 37.0% higher than those of the older adults for those simpler patterns (overall d' values were 1.510 and 1.102, respectively). There were no other significant effects (i.e., no significant age × noise or age × noise × complexity interactions). Another way to think about this effect of age concerns thresholds—for example, the magnitude of stimulus complexity that produces a particular level of performance (e.g., a d' value of 1.0) for the younger and older observers. Notice in Figure 4 (see the dashed lines) that for older adults, their pattern detection performance dropped to a threshold value (e.g., a d' value of 1.0) by a complexity value of 5.0 whereas the younger adults did not drop to that same threshold level of performance until they had reached a complexity value of 10.5; younger adults could therefore tolerate additional stimulus complexity (more than the older adults could tolerate) while performing at the same threshold level.

It is true that the observers' detection performance was relatively low (overall d' values were <0.6) for the more complex patterns (see right side of Figure 4). However, the observers did perform above chance for the three most complex patterns (patterns 21, 24, & 19). One sample t-tests revealed that the observers' d' values were significantly above zero (t values were 6.46, 3.75, & 2.52, $df = 35$, all $ps \leq 0.008$, one-tailed).

Results for the individual younger and older observers are shown in Figure 5. Given the significant

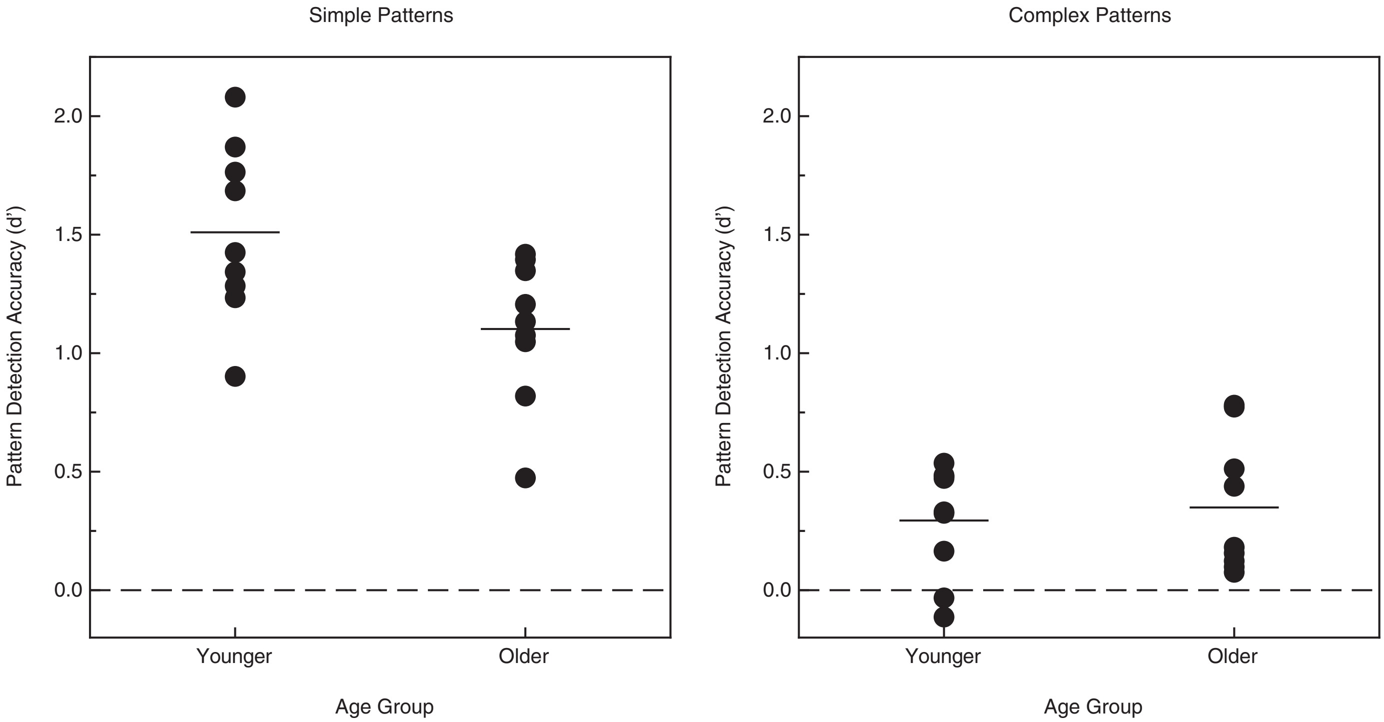

Figure 5. Individual observers' overall pattern detection accuracies (d' values) obtained for the four most simple patterns (left panel) and the four most complex patterns (right panel). The horizontal line segments indicate the mean performances for each age group and stimulus condition (simple versus complex stimulus patterns). The dashed lines indicate chance pattern detection performance (i.e., d' values of zero).

age × complexity interaction previously described, the pattern detection performances for the younger and older adults are shown separately for the four most simple patterns (left panel) and the four most complex patterns (right panel). The interaction between age and stimulus complexity is readily evident. One can also see that although there was an age-related difference in performance for the simple patterns, that the distributions for the younger and older observers overlap to a considerable degree. Thus some individual older adults matched or outperformed some of the younger adults.

Discussion

In their 2008 study, Blake et al. found large effects of age for a shape discrimination task when the object shapes were defined by differences in the simultaneity of reversals of local motion direction (i.e., temporal structure, TS); no such age effect was found when motion was irrelevant and the same shapes were defined by differences in average luminance. Their hypothesis was that "differences in performance between our two participant groups on the TS task may have to do with the strength or the precision of the time-varying neural signals generated by TS in these displays." This hypothesis is consistent with the reliable effects of age obtained for many motion-related tasks (for a review, see Billino & Pilz, 2019).

With regards to the perception of static shape/pattern (where motion does not exist or is irrelevant), the results of the current study are in some ways similar to and in some ways different from those of Blake et al. (2008). In similarity to Blake et al., the pattern detection performance obtained for many of our older adults matched or exceeded that exhibited by some of the younger adults (see Figure 5). Despite the extensive overlap between the distributions of the younger and older adults' pattern detection accuracies, there was nevertheless a significant adverse effect of age, particularly for the simpler patterns (see Figure 4). It is important to keep in mind that even our relatively simple patterns (e.g., patterns 10, 27, and 7) were more complex than the rectangular figures used by Blake et al.

The overall results of the current study do replicate the findings of Uttal and Tucker (1977)—there were significant adverse effects of both increasing stimulus complexity and amount of noise/camouflage. This replication is important, since there were only three (experienced) observers in the original experiment conducted by Uttal and Tucker. The fact that we

obtained essentially identical results with 18 naive observers demonstrates that the original findings of Uttal and Tucker are valid. As can be seen from Figures 2–5, the effects of stimulus complexity were large and systematic. Indeed, there was a strong correlation (Figure 3) between log stimulus complexity and the observers' pattern detection performance—the higher the complexity, the lower the performance. Because the correlation coefficient (Pearson r) was −0.95, that indicates that more than 90% of the variations in pattern detection performance ($0.95^2 = 0.9025$) can be accounted for by variations in stimulus complexity. An inspection of Figure 3 shows that a linear function describes the data quite well, except perhaps for Pattern 26 (fourth data point from the right). That particular pattern was more difficult to detect for our observers than it should be, according to its complexity. Interestingly, this result also occurred in the original experiment by Uttal and Tucker (1977, see their figure 4). We speculate that Pattern 26 may be more difficult to detect because this pattern is "disconnected" (i.e., consists of three separate, and unconnected, diagonal lines).

There was an adverse effect of age in the current experiment, but it was only consistent for the simpler patterns. The younger and older observers' detection performance was essentially equivalent for the four most complex patterns (e.g., see Figure 5). This outcome (that the adverse effects of age were most evident for easier conditions and did not exist for difficult conditions) is similar to that obtained by Norman and Higginbotham (2020, see their Figure 4). At first glance, this outcome seems puzzling and different from what one might expect. For example, as described earlier in the introduction, Habak and Faubert (2000) found that there was no adverse effect of age for simple stimuli (gratings defined by first order information, luminance), but a significant effect of age did occur for more complex stimuli (second order or contrast-defined gratings). It is, of course, true that the discrimination of orientation of gratings (whether luminance-defined or contrast-defined) is quite a different task than detecting dotted stimulus patterns that vary in shape (Figure 1). Nevertheless, the overall findings of the current experiment fall in an expected direction. Consider the functions relating the younger and older observers' detection performance to variations in stimulus complexity (Figure 4). Note in particular the dashed lines (in Figure 4) that delineate threshold performance (in our case, a d' value of 1.0). Notice that the older observers drop to a threshold level of pattern detection performance by a stimulus complexity of 5.0 (as indicated by the dashed red lines), whereas the younger observers' analogous detection performance does not fall to threshold levels until a stimulus complexity of 10.5 is reached. The younger observers in our study were able to tolerate much higher shape complexity and still perform well at pattern detection. One would have expected (in advance of the study) that if there are age-associated deficits in pattern detection, that older observers would not be able to tolerate as much pattern complexity as younger adults and still be able to perform at the same level, and this is indeed the outcome that we obtained.

Despite the fact that our current task (detection of patterns that varied in shape and complexity, see Figure 1) was quite different than the task of Roudaia, Farber, Bennett, and Sekuler (2011, detection of a C-shaped object, their Experiment 2), our two studies are nevertheless similar in that both demonstrate an adverse effect of age in detecting objects embedded in noise. The experiments across the two studies were also quite different in another way—we varied the difficulty of the task to examine its effects upon performance (see Figures 2–5), whereas Roudaia et al. (2011) varied the stimulus duration to produce a given fixed (75% correct) level of performance. The effect of age on pattern detection must be quite robust to manifest itself similarly in such two very different studies.

Another interesting finding of the current study is that the younger and older adults were similarly affected by the noise in the visual stimuli (e.g., there was no significant age × noise interaction). The younger observers' d' values dropped by 48.0% (mean d' values dropped from 1.187 to 0.617) as the amount of noise increased (from 15 to 30 obscuring noise dots); the analogous drop in d' values for the older observers was almost exactly the same, 48.1% (mean d' values dropped from 0.955 to 0.496). Although it is true that our younger and older observers were similarly affected by *external* noise (i.e., noise dots in the experimental stimuli), it is likely that the age effects that we did observe (reduction in detection performance for the older observers for the simpler stimulus patterns, see Figure 4) was due to increased *internal* noise within the visual system. Patrick Bennett and colleagues (e.g., Bennett et al., 2007; Creighton, Bennett, & Sekuler, 2024) have demonstrated for a variety of tasks that many age-related deficits in visual performance are associated with increased additive internal noise. This conclusion is reinforced by neurophysiological changes observed in neuronal functioning in visual cortex, such as reduced selectivity and increased spontaneous activity of visual neurons in senescent primates (Leventhal, Wang, Pu, Zhou, & Ma, 2003; Schmolesky, Wang, Pu, & Leventhal, 2000; Yu, Wang, Li, Zhou, & Leventhal, 2006).

When the results of the current study are considered as a whole, the adverse effects of age on pattern

perception appear to be quite modest. As just mentioned, the older and younger adults' performance was affected in an almost identical manner by variations in camouflaging noise, and both age groups were also affected similarly by complexity (see Figure 4). Given the large changes that occur with aging in areas devoted to perception in the cerebral cortex, such good performance by the older adults in our study may be considered surprising. For example, there is reduced gray matter (and connecting white matter) in the occipital, parietal, and temporal lobes of the cerebral cortex (Yang et al., 2016). Of particular interest are the substantive age-related reductions in the size/area of primary visual cortex and extrastriate areas V2 and V3 (Chang et al., 2015). The relatively good performance exhibited by the older adults in the current study demonstrates that the ability to recognize stationary patterns, even those embedded in substantial amounts of (external) noise, is quite resilient to the anatomical and physiological changes in the brain that accompany aging.

Keywords: pattern perception, complexity, shape

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